Analysis of the International Cooperation Network in Alternative Energy Production Technology Development Based on Co-Patents

Manuel Klauß[1]

[1] *HTWG Konstanz - University of Applied Sciences, Alfred-Wachtel-Straße 8, 78462 Konstanz, Germany, manuel.klauss@htwg-konstanz.de*

Abstract

This paper analyses international cooperation in alternative energy production research and development. Therefore, patents of the technological domain, registered at the European Patent Office from 1997 until 2016, are analysed. International cooperation is considered when patents involve co-assignment or co-inventorship comprising two or more different countries. Generally, international R&D cooperation tends to be increasing over time in alternative energy production. In total, 2234 co-patents from 87 countries are identified. Through social network analysis the cooperative relationships between countries are examined. The most significant states of the network are the United States of America and Germany. Innovative clusters and strong partnerships are identified. Alternative energy technologies that involve international cooperation most extensively are harnessing energy from manmade waste, solar energy and bio-fuels. The paper clarifies which countries are cooperating with each other for what purpose. The findings can be used for establishing R&D strategies in the domain of alternative energy production.

Keywords

Cooperation Network, Alternative Energy Production, Patent Analysis, Co-Patenting, Social Network Analysis

1 Introduction

Against the background of climate change, environmental pollution and the scarcity of fossil resources our society faces new global challenges [EEA 2012; van der Linden, et al. 2015; Kriegler, et al. 2016; Melander 2017]. Energy production and consumption is one of the major areas that need to be considered in this context [Cherp, et al. 2016]. Despite some positive developments in the last years, energy-related carbon dioxide emissions, coal production and its environmentally unfriendly consumption continued their trend of increasing annually [CCPI 2019]. Fossil resources are the basis of about 80 percent of the global energy production [REN21 2015]. At the same time, emerging economies like China or India are driving the growing global energy demand [IEA 2010]. China thereby makes up for a significant share of global energy consumption while being rated poorly regarding their greenhouse gas emissions [IEA 2010; CCPI 2019]. In a nutshell, a growing energy consumption, its environmentally harmful production and the dependency on limited resources are major challenges of today’s world.

Alternative or renewable energy production technologies can be one solution to face the described challenges and achieve sustainability. They do not harm the environment as extensively as conventional technologies and rely on sources that do not deplete. If renewable energy replaced fossil-fuel-based production, greenhouse gas emissions and the dependency on scarce resources could be reduced [Owusu, Asumadu-Sarkodie 2016; Cherp, et al. 2016].

The share of renewable energy production increased over the last years, but the world is still dependent on conventional, non-sustainable technology [CCPI 2019]. In fact, global renewable energy production increased substantially from 2004 to 2014. In this period, the global capacity of alternative energy production grew from 800 to 1712 Gigawatts and thus more than doubled [REN21 2015]. Still, there is a high potential and demand for green, environmentally friendly energy generation.

Research and development (R&D) may enhance alternative energy production and make it more efficient. Technological innovation can lead to lower costs and thus to more attractive ecological substitutes for conventional energy production [Noailly, Smeets 2015].

Cooperation in research and development is widely regarded to be a promotor and accelerator for innovation and technological development [e.g. Belderbos, et al. 2004; Faems, et al. 2005; Lucena, García-Fontes 2005; de Sousa, et al. 2015; Klímová, Žítek 2016]. Through sharing knowledge, resources, skills, costs and risks between partners, cooperative R&D can lead to innovative breakthroughs [Belderbos, et al. 2004].

Consequently, cooperation can be one enabler for achieving sustainable development through innovation. This research paper aims for analysing the global cooperation network in alternative energy production technology development on a country-wise aggregation level. It clarifies who cooperates with whom for what purpose and identifies cooperative clusters among countries.

2 Literature Review

Every innovative organization at least to some extent is connected to a cooperation or knowledge network or is part of a sectoral innovation system. No innovation is implemented in absolute isolation [Cooke, et al. 1997; Malerba 2002; Mondal, et al. 2010; Melander 2018]. Cooperation with external partners has become important for research and development projects [Beaudry, Schiffauerova 2011; Petroni, et al. 2012]. Archibugi and Iammarino [2002] emphasize the international aspect of this phenomenon and call it global technological collaboration.

Based on the literature, technological cooperation or collaboration can be defined as a set of actions for which two or more partners combine their material or immaterial resources to meet goals they agreed on. These resources mostly involve technical or scientific knowledge or skills and the objective is creating new technical knowledge, products or processes [Tyler, Steensma 1995; Archibugi, Iammarino 1999; Nummela 2003; Archibugi, Pietrobelli 2003; Yamin, Otto 2004; Lucena, García-Fontes 2005; Goetze 2010]. Although there are formal differences between cooperation and collaboration, cooperation in this paper is used as an umbrella term for all activities that are in accordance with the aforementioned definition.

Partners among technological cooperation can be of different kinds. For example, there can be cooperative relations between industrial companies, universities or private as well as public research institutions [Gao, et al. 2011; Rantala, Ukko 2018**].**

Generally, cooperation with external partners with the aim for the generation of innovation is more and more becoming common [Petroni, et al. 2012]. Dachs and Pyka [2009] find an intensifying internationalisation of innovation processes through increasing cooperation among EU-member states and between European countries with the United States of America.

The reasons for this growing importance are manifold. International cooperative relationships enable their partners to find new external sources of knowledge on a global scale **[**Archiburgi, Iammarino 2002]. Some researchers describe cooperative R&D activities as acts of open innovation that allow compensating internal knowledge gaps using external inputs [Dittrich, Duysters 2007; Abulrub, Lee 2012; de Paulo, et al. 2018].

A cooperative partnership can lead to a substantial improvement of innovative capabilities [Belderbos, et al. 2004; Faems, et al. 2005; Lucena, García-Fontes 2005; de Sousa et al. 2015; Klímová, Žítek 2016]. The involvement of external inputs leads to a diversification of skills and fosters creativity. Thus, it speeds up an organization’s innovative processes and increases its technological output [Geum, et al. 2013].

Despite the advantages, there also are some drawbacks to cooperation. For example, Broekel et al. [2015] argue that establishing and maintaining such partnerships tends to be costly and the success of cooperative research and development projects is not guaranteed.

Also, there may be unintended knowledge transmissions. This means, valuable internal knowledge of the one partner is probably made available to the other one through cooperation [Kesteloot, Veugelers 1995; Broekel, et al. 2015]. This can occur both directly and indirectly if there is a network of several partners cooperating with each other [Wanzenböck, et al. 2014].

However, the literature mostly emphasizes positive aspects of cooperative innovation. Researchers argue that such activities can provide economical advantages for the partners. Both risks and costs of R&D projects can be shared [Nummela 2003; Belderbos, et al. 2004]. R&D cooperation thus can lead to a better profitability of companies [Kesteloot, Veugelers 1995].

As defined, a single act of cooperation involves two or more parties interacting with each other. All of these parties may have multiple cooperative relationships simultaneously. Consequently, network structures emerge. Many researches focus on analysing the characteristics of such networks for cooperative R&D projects. Literature in this domain is extensive and can be categorized using the following categories: Perspective on the cooperative network, focus of the network, aggregation level and approach towards analysing the network. In the following, existing studies are pointed out and classified using the aforementioned categories.

Depending on the definition of system boundaries or more specifically the chosen perspective, networks can be considered differently. Cooperation networks can be analysed on a global, a transnational, a national or a regional level [Binz, Truffer 2017]. For example, Calero et al. [2007], de Prato and Nepelski [2012] or de Paulo et al. [2018] examine technological cooperation networks with a global perspective. Other researches, such as Hazir and Autant-Bernard [2014] concentrate their cooperation network analysis on the transnational area of Europe. Hoekman et al. [2010] as well as Crespo et al. [2016] also take a transnational perspective for their analyses. Many other authors, such as Balconi et al. [2004], Gao et al. [2011], Xuefeng and Yougou [2012], Liu et al. [2012], Eslami et al. [2013], Chen et al. [2013], Wanzenböck et al. [2014] or Klímová and Žítek [2016] take a perspective on a single country while analysing cooperative R&D networks. Cantner and Graf [2006] choose an even closer, regional perspective and define their system boundaries at the level of a single German city.

While examining cooperation networks, researchers choose different foci. For example, analyses can be focused on certain technologies or industries. The focus thus defines the reason or field a cooperation network exists for. For example, Eslami et al. [2013], Hazir and Autant-Bernard [2014] or Pereira et al. [2018] focus their network analyses on biotechnology, while Calero et al. [2007] choose the domain of bio-pharmaceutics. Beaudry and Schiffauerova [2011] as well as Zheng et al. [2014] focus cooperation in nanotechnology. Crespo et al. [2016] analyse the cooperation network in the mobile phone industry. Some studies do not focus anything specifically but rather analyse structures of cooperation networks in general [e.g. de Prato, Nepelski 2012; Wanzenböck, et al. 2014].

Existing studies of the domain also differ concerning their aggregation level. Some researchers examine networks between humans, others aggregate cooperative activities on a company-wide or geographical level. For example, de Prato and Nepelski [2012], Xuefeng and Yougou [2012], Zheng et al. [2014] and de Paulo et al. [2018] choose a country-wise aggregation for their cooperation network analyses and thus sum up all cooperative actions per country. Wanzenböck et al. [2014] define 241 European regions as their level of aggregation. Gao et al. [2011] use Chinese provinces and thus also a regional aggregation level. Cantner and Graf [2006] aggregate their data on the level of patent assignees and consequently humans or legal persons.

There are two significant approaches how researchers determine and analyse cooperative research and development networks. A first approach towards analysing such networks is based on co-authorships of scientific research papers [e.g. Wagner, Leydersdorff 2005; Zare-Farashbandi, et al. 2016; Fagan, et al. 2018]. This research-paper-based approach can be characterised as rather be focused on scientific networks than on technological cooperation.

A second common approach is based on patent analysis. It is argued that patents are the result of research and development or innovative actions in general [Eaton, Kortum 1996]. Thus, they can be used as an indicator for R&D activities. Some researchers analyse innovation networks through examining patent citations [e.g. Jaffe, et al. 1993; Yan, Guan 2018]. Others examine patents which involve two or more assignees, applicants or inventors from different aggregation levels [e.g. Maggioni, Uberti 2008; Goetze 2010; de Prato, Nepelski 2012; Broekel, et al. 2015]. These so-called co-patent networks provide information on knowledge flows between the cooperating partners [Goetze 2010].

As described in the introduction of this paper, alternative energy production is one of the technological areas that need to be developed and applied on a large scale in order to face challenges of global warming and environmental pollution. International cooperation in R&D may be one lever to foster innovation and meet existing technological needs.

Melander [2018] analyses cooperation for green product innovation and finds out that all regarded partners are situated in a cooperation network. It can be concluded that cooperation in fact is important in the area of green technology and thus for alternative energy production.

There are some more detailed studies on cooperative R&D networks in the area of alternative energy production. However, most do not analyse the domain holistically but rather focus single technologies of the area. For example, de Paulo and Porto [2017] analyse the innovation network for solar energy technologies and de Paulo et al. [2018] focus cooperation networks in photovoltaic development. Both studies identify distinct international cooperation networks.

Cantner et al. [2016] analyse German inventor networks for renewable energy technology in general. They focus changes to the network's structure as changes in the national environmental policies occur. Their findings show clear impacts of policy changes on cooperation network characteristics.

Johnstone et al. [2010] examine technological innovation in the area of renewable energy. They also focus different policies and their influence on patent counts for different technologies. The researchers find rising innovation in renewable energy technology and identify Germany, the United States of America and Japan as most active innovators [Johnstone, et al. 2010].

The available literature does not involve any study with a global perspective about cooperative R&D networks with a focus on alternative energy production in general. Existing studies either have a narrower focus or a closer perspective. Consequently, characteristics of the global cooperation network in alternative energy production technology development are not fully known. This paper thus aims to determine and analyse the structures of the network.

This is carried out with a country-based aggregation level to find out where major cooperative innovation areas are located. This especially makes sense because there are geographic knowledge spill overs caused by cooperation [Wanzenböck, et al. 2014]. Geographical knowledge diffusion or spill overs may also occur because of employees switching between companies within a certain region or because of cooperation with specialised consultancies that are active in a certain geographical location [Breschi, Lissoni 2009]. Shared knowledge spreads over the involved regions. Consequently, countries with high general expertise in certain technological domains emerge as they are involved in cooperative research and development.

This paper provides a holistic analysis of the cooperative R&D network for all relevant types of alternative energy production technology with a global perspective. The analysis reveals which countries have cooperative relationships of what kind with each other and which innovative clusters exist. As described, heavy involvement in cooperative R&D implies expertise in particular technologies. On this basis, countries that provide extensive know-how for certain renewable energy production technologies are determined.

This has not been examined, yet. Thus, the findings are valuable for both academic and industrial purposes. The results of this paper can be used for further studies or for deriving strategies for R&D projects in the technological domain of alternative energy production.

3 Research Methods and Results

To find out international cooperative relationships, patent data is used. As described in the literature review, patents are one of the predominant sources for analysing cooperative research and development networks. They are an indicator for successful research and development activities or the innovative output of an organization and thus provide a good basis for the analysis [Eaton, Kortum 1996]. Patent data is objective and easily accessible, because it is in a patent’s nature to be publicly available [Yan, Guan 2018]. Also, patent data is discrete and in a convenient, standardised format that can easily be used for analyses [Johnstone, et al. 2010].

For identifying international cooperation, co-patents are regarded. Each patent includes a list of applicants and inventors. These can be legal entities or natural persons. In this analysis, cooperation is considered if there are two or more applicants or inventors listed for one patent. There is international cooperation, if these persons or legal entities are from different countries.

For gathering the co-patent data, the European Patent Office (EPO) PATSTAT Global database is used. It is a reliable and extensive source as it involves more than 100 million patent documents from more than 40 patent authorities [EPO 2019]. Structured query language is used for the collection of data.

Only patents that are registered directly at the EPO are considered. This is for achieving a uniform database that does not involve redundant records. As the analysis focuses international co-patents, it is likely that they are registered directly at the EPO which simplifies the procedure of achieving patent rights in all European member states [Johnstone, et al. 2010]. Every country within the database is counted. Patents that are only registered at authorities other than the EPO are not regarded. This leads to better data quality, but also to a Europe-centric, global network.

To further ensure not to count any international co-patents redundantly, patent families are analysed. Each patent family identification number is considered only once.

As a timeframe for the analysis, the beginning of 1997 until the end of the year of 2016 is chosen. For this period, there is adequate data available in the EPO PATSTAT Global database. Furthermore, a timeframe of twenty years appears to be a reasonable period for the analysis.

For identifying patents of the area of alternative energy production technology, International Patent Classification (IPC) classes are used. These involve a standardised system to classify patents according to their technological fields [WIPO 2018]. For this paper, IPC classes of the IPC Green Inventory are used for obtaining patents from the technical domain of alternative energy production. The Green Inventory is a list of IPC classes developed by a committee of experts that includes all classes relevant for certain green technologies [WIPO 2017].

Technologies that are considered by this method are bio-fuels, integrated gasification combined cycle, fuel cells, pyrolysis or gasification of biomass, harnessing energy from manmade waste, hydro energy, ocean thermal energy conversion, wind energy, solar energy, geothermal energy, other production or use of heat (not derived from combustion), using waste heat and devices for producing mechanical power from muscle energy. They involve 296 unique IPC classes.

After applying this method, 2234 co-patents from 87 different countries are identified. These co-patents involve 3028 bilateral cooperative relationships between countries. 408 co-patents involved more than two different countries of origin of their inventors or applicants.

Figure 1 provides information on the number of annual co-patent applications per considered technology. Integrated gasification combined cycle, geothermal energy and ocean thermal energy conversion as well as using waste heat and devices for producing mechanical power from muscle energy are not included due to a lack of international co-patents in the considered time period. All data depicted refers to the scale on the left axis of the diagram, except the overall data which is related to the right scale. Overall thereby reflects the annual sum of all co-patent applications of all considered alternative energy production technologies. Linear (Overall) depicts the linear regression line of the overall data and thus shows its trend.

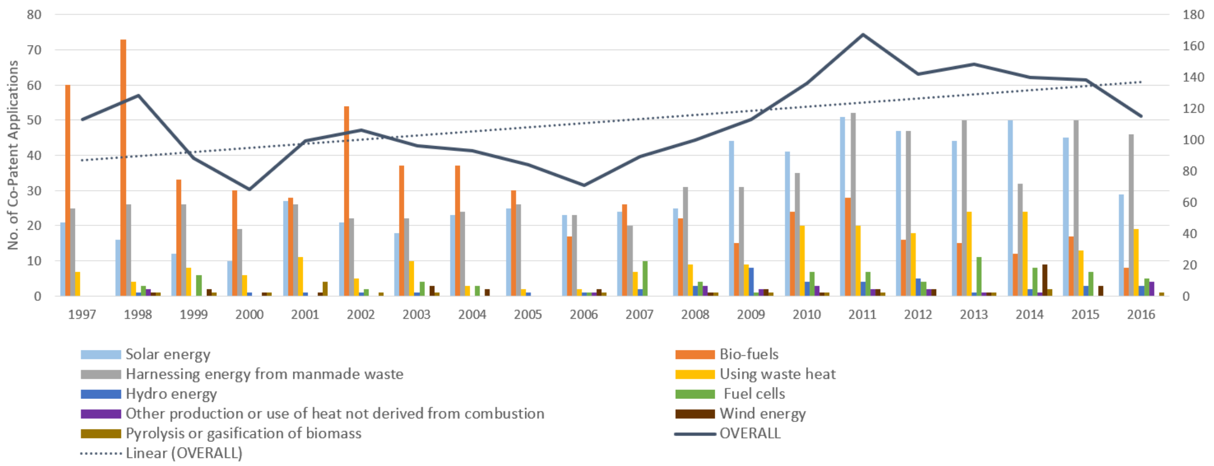

Figure 1: Annual Co-Patent Applications per Alternative Energy Production Technology

Table 1 provides further information on the characteristics of the identified co-patents and the derived cooperative research and development partnerships. The most common alternative energy production technologies within the gathered co-patent data are listed. The top three cooperating countries are calculated using the number of cooperative relationships, the countries are involved in for R&D in the technological area. This count also is displayed in the table.

	No. of Co-Patents	No. of Cooperation	Top 3 Countries Cooperating
Energy from manmade waste	633 (28.3% of all)	810 (27.6% of all)	USA (385), Germany (220), France (124)
Solar energy	596 (26.7% of all)	784 (26.7% of all)	USA (292), Germany (286), France (115)
Bio-fuels	582 (26.0% of all)	792 (27.0% of all)	USA (485), United Kingdom (174), Germany (155)
Using waste heat	211 (9.4% of all)	277 (9.4% of all)	Germany (111), USA (84), Switzerland (58)
Fuel cells	83 (3.7% of all)	120 (4.1% of all)	USA (69), Germany (33), United Kingdom (25)

Table 1: Cooperation Characteristics per Alternative Energy Production Technology

Social network analysis (SNA) is widely used for analysing cooperation networks [Fagan, et al. 2018]. It is also applied in this research paper. The methodology allows analysing the relationships between different instances. SNA is based on graph theory and aims for deriving a model or a graphical representation of a network by means of a directed or undirected graph that consists of nodes and edges representing partners and their relationships [Sternitzke, et al. 2008].

This study uses a country-wise aggregation level. Thus, nodes of the network graph represent countries. Edges illustrate cooperative relationships between the countries by the means of co-patents that involve the states. Figure 2 depicts the graph of the identified cooperation network.

The larger a node in the network graph, the higher is the individual country's significancy within the network. Significance thereby is defined by a node's degree. Latter is a measure of network theory and implies how many connections a single node involves. [Opsahl, et al. 2010].

The thicker an edge is, the larger is its weight. Weight thereby is defined as the number of identified co-patents that involve the two countries the edge is connected to. Thick edges thus indicate an intense cooperative relationship. Edges also are colour coded indicating the alternative energy production technology the two countries most often cooperated for in the considered time period. The colour coding is explained in the legend of the diagram. Colours of the nodes represent clusters. These are identified by modularity. This means, the clusters involve groups of states that established distinct relationships among each other.

The network graph is created using GEPHI, an open-source tool for social network analysis [de Paulo, et al. 2018]. A threshold of five co-patents for edges to be displayed is applied. This is to increase clarity of the graph. Consequently, the graph includes 44 of the 87 total nodes and 346 edges. Latter is equivalent to 81.6% of all identified edges. The average degree of nodes is 15.73. Further quantitative, statistical measures can be found in Table 2 in the appendix of this paper.

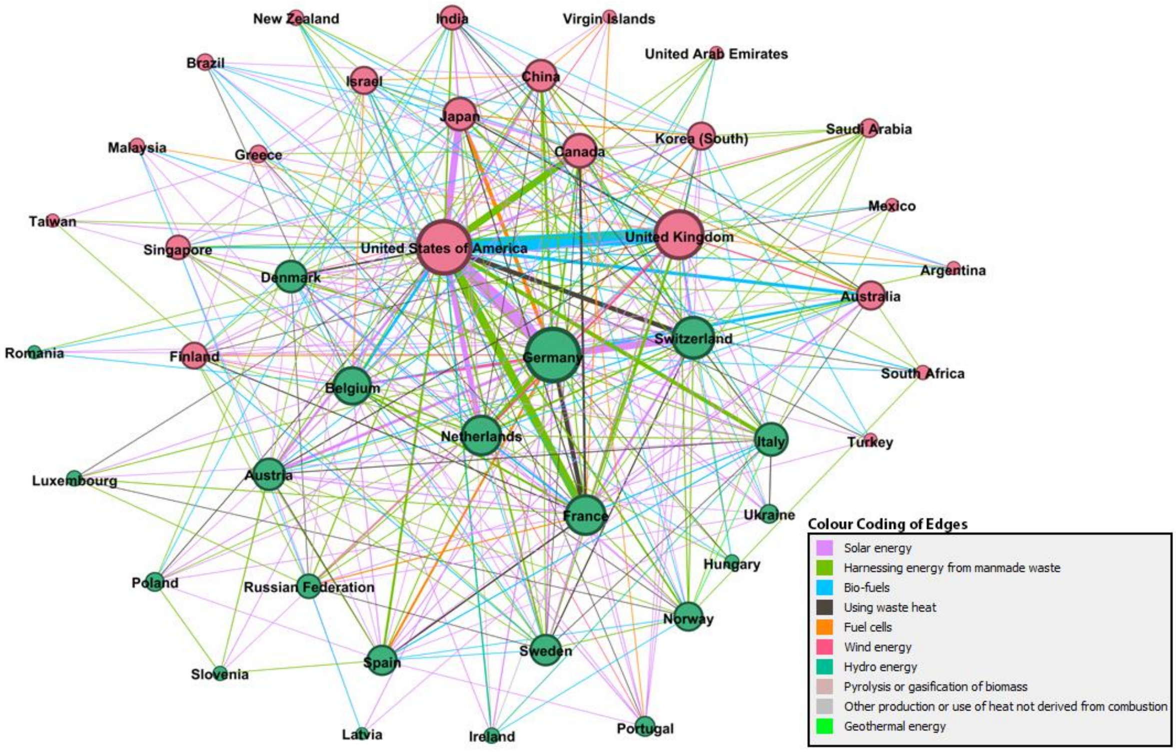

Figure 2: Graph of the Cooperation Network in Alternative Energy Production Development

4 Discussion

Co-Patenting and thus cooperation in research in development in the technological domain of alternative energy production shows a trend of increasing over the time period from 1997 to 2016 as shown by the linear regression in Figure 1. This matches the literature that emphasises a growing importance of cooperation in R&D [Petroni, et al. 2012; Dachs, Pyka 2009].

The analysis shows that cooperation is not evenly distributed among the considered technologies of alternative energy production. Harnessing energy from manmade waste, solar energy and bio-fuels by far are most common in international cooperative R&D as Table 1 and Figure 1 imply. Also, Figure 1 shows time-dependent changes in the extent of cooperation per technology. In the beginning of the considered period, bio-fuels made up for most of the cooperation. With little variances, cooperation for this technology decreased over time. Solar energy and harnessing energy from manmade waste show a significant growth in cooperation starting around 2009.

Table 1 clarifies that Germany and the United States of America are among the most in cooperation involved countries for all the major alternative energy production technologies. Their important role for the cooperation network can also be verified by the SNA. The network graph shown in Figure 2 illustrates the states' central roles in the cooperation network. As shown in Table 2 in the appendix, the two countries also involve the highest degree and centrality measures. Thus, they are the most significant partners of the network.

The social network analysis further reveals the United Kingdom, Switzerland, France, the Netherlands, Belgium, Canada and Japan as important countries of the network. This mostly matches the findings of Johnstone et al. [2010] who identify countries that are most innovative in the technological domain of renewable energy in terms of patent counts.

It is noticeable that most of these important cooperative states are European. The reason therefore may be the consideration of EPO-patents only. However, Dachs and Pyka [2009] also find strong cooperation among European countries and between Europe and the United States of America. This is also true for the analysed cooperation network for alternative energy production technology development. The identified clusters show one group that involves mostly European countries. This cluster is represented by green nodes in Figure 2. Thus, European countries of the analysed network show intense cooperative partnerships with each other. Also, the SNA indicates that there is heavy cooperation between Europe and the United States. This can also be seen in the graph shown in Figure 2. There are many thick edges and thus many co-patents involving the USA and European countries.

The SNA further reveals countries that have intense cooperative partnerships for R&D in alternative energy production technology. Germany and the USA show a profound cooperative relationship. Same is true for Germany and Switzerland, the USA and the United Kingdom as well as the USA and Canada. Japan and the USA as well as France and the USA also cooperate heavily. Again, the central roles of Germany and the USA stand out.

It can be concluded that countries listed in the network graph tend to have expert knowledge in the technological domains they have cooperated in. The reason for this assumption is the existence regional knowledge spill over effects [Wanzenböck, et al. 2014; Breschi, Lissoni 2009]. The higher the involvement in cooperative R&D of a country, the likelier it is that it provides extensive knowledge in the technology. Consequently, the aforementioned countries most likely provide expertise in renewable energy technology. Technology-wise, the most in cooperation involved countries listed in Table 1 can be regarded as areas of highest expertise for the specific alternative energy production technology.

There are some limitations to the patent-based approach. Johnstone et al. [2010] point out that not every patent involves the same innovative value or importance. Also, patenting is not carried out equally extensive in different countries [Johnstone, et al. 2010]. Bergek and Bruzelius [2010] argue that co-patents are no unambiguous indicator for international cooperative activities. It must be acknowledged that the modelled network may not display the real network perfectly.

However, co-patents that include different countries always involve international cooperation to some extent. A knowledge transfer between partners happened and was comprehensive enough to lead to a patentable innovation [Maggioni, Uberti 2008; Goetze 2010]. Thus, the modelled network and the analysis at least is based on a subset of the real cooperation network and consequently provides a sufficient level of accuracy. Yet, rather than a truly global cooperation network, a Europe-centric, global network is modelled and analysed.

5 Conclusion

This paper analysed the Europe-centric, global cooperation network in alternative energy production technology research and development based on international EPO co-patents. Generally, cooperative R&D in the domain tends to increase. Germany and the United States of America are identified as most cooperative states. Other important partners in the cooperation network are the United Kingdom, Switzerland and France. Cooperation is most common in the domains of solar-energy, harnessing energy from manmade waste and bio-fuels.

It further clarifies, which states are cooperating with each other for R&D in which alternative energy production technology. Major cooperative relationships, clusters and areas of high technological expertise are identified. This knowledge on the cooperation network for alternative energy production development was not existent before. The findings can be used for deriving R&D strategies for companies, universities or research institutions. Also, this paper may be the basis for further studies. For example, the identified, country-wise cooperative relationships and clusters could be examined using a more detailed aggregation level.

References

Abulrub, A; Lee, J. (2012) Open innovation management: challenges and prospects. Procedia – Social and Behavioral Sciences, Vol 41, 2012, p. 130-138.

Archibugi, D; Iammarino, S. (1999) The policy implications of the globalisation of innovation. Research Policy 28, Vol 28, Issues 2–3, 1999, p. 317-336.

Archibugi, D; Iammarino, S. (2002) The globalization of technological innovation: definition and evidence. Review of International Political Economy, Vol 9:1, 2002, p. 98-122.

Archibugi, D; Pietrobelli, C. (2003) The globalisation of technology and its implications for developing countries: Windows of opportunity or further burden?. Technological Forecasting and Social Change, Vol 70, Issue 9, 2003, p. 861-883.

Beaudry, C; Schiffauerova, S. (2011) Impacts of collaboration and network indicators on patent quality: The case of Canadian nanotechnology innovation. European Management Journal, No 29, 2011, p. 362-376.

Balconi, M; Breschi, S.; Lissoni, F. (2004) Networks of inventors and the role of academia: an exploration of Italian patent data. Research Policy, Vol 33, Issue 1, 2004, p. 127-145.

Belderbos, R; Carree, M; Lokshin, B. (2004) Cooperative R&D and firm performance. Research Policy, Vol 33, Issue 10, 2004, p. 1477-1492.

Bergek, A; Bruzelius, A. (2010) Are patents with multiple inventors from different countries a good indicator of international R&D collaboration? The case of ABB. Research Policy, Vol 39, Issue 10, 2010, p. 1321-1334.

Binz, C; Truffer, B. (2017) Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. Research Policy, Vol 46, Issue 7, 2017, p. 1284-1298.

Breschi, S; Lissoni, F. (2009) Mobility of skilled workers and co-invention networks: an anatomy of localized knowledge flows. Journal of Economic Geography, Vol 9, Issue 4, 2009, p. 1-30.

Broekel, T; Brenner, T; Buerger, M. (2015) An Investigation of the Relation between Cooperation Intensity and the Innovative Success of German Regions, Spatial Economic Analysis, Vol 10, No 1, 2015, p. 52-78.

Calero, C; van Leeuwen, T; Tijssen, R. (2007) Research cooperation within the bio-pharmaceutical industry: Network analyses of co-publications within and between firms. Scientometrics, Vol 71, No 1, 2007, p. 87-99.

Cantner, U; Graf, H. (2006) The network of innovators in Jena: An application of social network analysis. Research Policy, Vol 35, Issue 4, 2006, p. 463-480.

Cantner, U; Graf, H; Herrmann, J; Kalthaus, M. (2016) Inventor networks in renewable energies: The influence of the policy mix in Germany. Research Policy, Vol 45, Issue 6, 2016, p. 1165-1184.

Chen, J; Jang, S-L; Chang, C-H. (2013) The patterns and propensity for international co-invention: the case of China. Scientometrics, Vol 94, Issue 2, 2013, p. 481-495.

Cherp, A; Jewell, J; Vinichenko, V; Bauer, N; De Cian, E. (2016) Global energy security under different climate policies, GDP growth rates and fossil resource availabilities. Climate Change, Vol 136, Issue 1, 2016, p. 83-94.

CCPI (2019) Climate Change Performance Index – Results 2019. Germanwatch, NewClimate Institute, Climate Action Network, 2019.

Cooke, P; Gomez Uranga, M; Etxebarria, G. (1997) Regional innovation systems: Institutional and organisational. dimensions. Research Policy, Vol 26, Issues 4-5, 1997, p. 475-491.

Dachs, B; Pyka, A. (2009) What drives the internationalisation of innovation? Evidence from European patent data. Economics of Innovation and New Technology, Vol 19, No 1, 2010, p. 71-86.

Crespo, J; Suire, R; Vicente, J. (2016) Network structural properties for cluster long-run dynamics: evidence from collaborative R&D networks in the European mobile phone industry. Industrial and Corporate Change, Vol 25, No 2, 2016, p. 261-282.

De Paulo, A; Porto, G. (2017) Solar energy technologies and open innovation: A study based on bibliometric and social network analysis. Energy Policy, Vol 108, 2017, p. 228-238.

De Paulo, A; Ribeiro, E; Porto, G. (2018) Mapping countries cooperation networks in photovoltaic technology development based on patent analysis. Scientometrics, Vol 117, Issue 2, 2018, p. 667-686.

De Prato, G; Nepelski, D. (2012) Global technological collaboration network. Network analysis of international co-inventions. European Commission – JRC IPTS, MPRA Paper, No. 38818, 2012.

De Sousa, A; Braga, M; Meyer, L. (2015) Impact of cooperation on the R&D activities of Brazilian firms. Procedia Economics and Finance, No 24, 2015, p. 172-181.

Dittrich, K; Duysters, G. (2007) Networking as a Means to Strategy Change: The Case of Open Innovation in Mobile Telephony. Journal of Product Innovation Management, Vol 26, Issue 6, 2007, p. 510-521.

Eaton, K; Kortum, S. (1996) Trade in ideas Patenting and productivity in the OECD. Journal of International Economics, Vol 40, 1996, p. 251-278.

EEA (2012) Climate change, impacts and vulnerability in Europe 2012: An indicator-based report. EEA Report, No 12, 2012.

EPO (2019) PATSTAT. WWW page. https://www.epo.org/searching-for-patents/business/patstat.html#tab-1. accessed 2.5.2019.

Eslami, H; Ebadi, A; Schiffauerova, A. (2013) Effect of collaboration network structure on knowledge creation and technological performance: The case of biotechnology in Canada. Scientometrics, No 97, Issue 1, 2013, p. 99-119.

Faems, D; Van Looy, B; Debackere, K. (2005) Interorganizational Collaboration and Innovation: Toward a Portfolio Approach. Journal of Product Innovation Management, Vol 22, Issue 3, 2005, p. 238-250.

Fagan, J; Eddens, K; Dolly, J; Vanderford, N; Weiss, H; Levens, J. (2018) Assessing Research Collaboration through Co-authorship Network Analysis. The Journal of Research Administration, Vol 49(1), 2018, p. 76-99.

Gao, X; Guan, J; Rousseau, R. (2011) Mapping collaborative knowledge production in China using patent co-inventorships. Scientometrics, Vol 88, Issue 2, 2011, p. 343-362.

Geum, Y; Lee, S; Yoon, B; Park, Y. (2013) Identifying and evaluating strategic partners for collaborative R&D: Index-based approach using patents and publications. Technovation, Vol 33, Issues 6-7, 2013, p. 211-224.

Goetze, C. (2010) An empirical enquiry into co-patent networks and their stars: The case of cardiac pacemaker technology. Technovation, Vol 30, 2010, p. 436-446.

Hazir, C; Autant-Bernard, C. (2014) Determinants of cross-regional R&D collaboration: some empirical evidence from Europe in biotechnology. The Annals of Regional Science, Vol 53(2), 2014, p. 369-393.

Hoekman, J; Frenken, K; Tijssen, R. (2010) Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe. Research Policy, Vol 39, Issue 5, 2010, p. 662-673.

IEA (2010) World Energy Outlook 2010. International Energy Agency, 2010, Paris, France.

Jaffe, A; Trajtenberg, M; Henderson, M. (1993) Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. The Quarterly Journal of Economics, Vol 108, No 3, 1993, p. 577-598.

Johnstone, N; Haščič, I; Popp, D. (2010) Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts. Environmental and Resource Economics, Vol 45, Issue 1, 2010, p. 133-155.

Kesteloot, K; Veugelers, R. (1995) Stable R&D Cooperation with Spillovers. Journal of Economics & Management Strategy, Vol 4, No 4, 1995, p. 651-672.

Klímová, V; Žítek, V. (2016) Competence centres as a method of innovation cooperation enhancement in the Czech Republic. Ekonomická Revue - Central European Review of Economic Issues, Vol 19, 2016, p. 77-86.

Kriegler, E; Mouratidaou, I; Luderer, G; Bauer, N; Brecha, R; Calvin, K; De Cian, E; Edmonds, J; Jiang, K; Tavoni, M; Edenhofer, O. (2016) Will economic growth and fossil fuel scarcity help or hinder climate stabilization? Overview of the RoSE multi-model study. Climatic Change, Vol 136, Issue 1, 2016, p. 7-22.

Liu, H-I; Chang, B-C; Chen, K-C. (2012) Collaboration patterns of Taiwanese scientific publications in various research areas. Scientometrics, Vol 92, Issue 1, 2012, p. 145-155.

Lucena, A; García-Fontes, W. (2005) "The production of complementarities among R&D activities and external collaboration: a knowledge-based view". Academy Winter 2005 PhD Conference, Aalborg University, 2005, Aalborg, Denmark.

Maggioni, M; Uberti, T. (2008) Knowledge networks across Europe: which distance matters?. The Annals of Regional Science, Vol 43, 2008, p. 691-720.

Malerba, F. (2002) Sectoral systems of innovation and production. Research Policy, Vol 31, Issue 2, 2002, p. 247-264.

Melander, L. (2017) Achieving Sustainable Development by Collaborating in Green Product Innovation. Business Strategy and the Environment, Vol 26, Issue 8, 2017, p. 1095-1109.

Melander, L. (2018) Customer and Supplier Collaboration in Green Product Innovation: External and Internal Capabilities. Business Strategy and the Environment, Vol 27, Issue 6, 2018, p. 677-693.

Mondal, A; Kamp. L; Pachova, M. (2010) Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh—An innovation system analysis. Energy Policy, Volume 38, Issue 8, 2010, p. 4626-4634.

Noailly, J; Smeets, R. (2015) Directing Technical Change from Fossil-Fuel to Renewable Energy Innovation: An Application Using Firm-Level Data. Journal of Environmental Economics and Management, Vol 72, 2015, p. 15-37.

Nummela, N. (2003) Looking through a prism—multiple perspectives to commitment to international R&D collaboration. Journal of High Technology Management Research, Vol 14, 2003, p. 135-148.

Opsahl, T; Agneessens, F; Skvoretz, J. (2010) Node centrality in weighted networks: Generalizing degree and shortest paths. Social Networks, Vol 32, Issue 3, 2010, p. 245-251.

Owusu, P; Asumadu-Sarkodie, S. (2016) A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Engineering, Vol 3:1, 2016.

Pereira, C; Lavoie, J; Porto, G. (2018) Technological cooperation network in biotechnology: Analysis of patents with Brazil as the priority country. Innovation & Management Review, Vol 15, No 4, 2018, p. 416-434.

Petroni, G; Venturini, K; Verbano, C. (2012) Open innovation and new issues in R&D organization and personnel management. The International Journal of Human Resource Management, Vol 23, No 1, 2012, p. 147-173.

Rantala, T; Ukko, J. (2018) Performance measurement in university–industry innovation networks: implementation practices and challenges of industrial organisations. Journal of Education and Work, Vol 31, No 3, 2018, p. 247-261.

REN21 (2015) Renewables 2015: Global Status Report. Renewable Energy Policy Network for the 21st Century, 2015, Paris, France.

Sternitzke, C; Bartowski, A; Schramm, R. (2008) Visualizing patent statistics by means of social network analysis tools. World Patent Information, Vol 30, Issue 2, 2008, p. 115-131.

Tyler, B; Steensma, H. (1995) Evaluating Technological Collaborative Opportunities: A Cognitive Modeling Perspective. Strategic Management Journal, Vol 16, Issue S1, 1995, p. 43-70.

Van der Linden, S; Leiserowitz, A; Feinberg, G; Maibach, E. (2015) The Scientific Consensus on Climate Change as a Gateway Belief: Experimental Evidence. PLos ONE, Vol 10(2): e0118489, 2015.

Wagner, C; Leydesdorff, L. (2005) Mapping the network of global science: comparing international co-authorships from 1990 to 2000. International Journal of Technology and Globalization, Vol 1(2), 2005, p. 185-208.

Wanzenböck, I; Scherngell, T; Brenner, T. (2014) Embeddedness of regions in European knowledge networks: a comparative analysis of inter-regional R&D collaborations, co-patents and co-publications. The Annals of Regional Science, Vol 53(2), 2014, p. 337-368.

WIPO (2017) IPC Green Inventory. WWW page. https://www.wipo.int/classifications/ipc/en/green_inventory/, accessed 2.5.2019.

WIPO (2018) Guide to the International Patent Classification – Version 2018. World Intellectual Property Organization, 2018, Geneva, Switzerland.

Xuefeng, W; Yougou, W. (2012) Co-inventor Analysis on China's international technology collaboration in US patent activities: 1976-2010. Procedia Engineering, Vol 37, 2012, p. 314-322.

Yamin, M; Otto, J. (2004) Patterns of knowledge flows and MNE innovative performance. Journal of International Management, Vol 10, Issue 2, 2004, p. 239-258.

Yan, Y; Guan, J. (2018) How multiple networks help in creating knowledge: evidence from alternative energy patents. Scientometrics, Vol 115, Issue 1, 2018, p. 51-77.

Zare-Farashbandi, F; Geraei, E; Siamaki, S. (2014) Study of co-authorship network of papers in the Journal of Research in Medical Sciences using social network analysis. Journal of research in medical sciences, Vol 19(1), 2014, p. 41-46.

Zheng, J; Zhao, Z-y: Zhang, X; Chen, D-z; Huang, M-h. (2014) International collaboration development in nanotechnology: a perspective of patent network analysis. Scientometrics, Vol 98, Issue 1, 2014, p. 683-702.

Appendix

	Closeness Centrality	**Betweenness Centrality**	**Degree**
Germany	0.98	137.43	42
United States of America	0.98	130.86	42
United Kingdom	0.88	75.96	37
Switzerland	0.78	34.56	31
France	0.75	30.22	29
Netherlands	0.75	29.50	29

Belgium	0.73	24.96	27
Canada	0.69	9.01	24
Japan	0.68	11.30	23
Italy	0.68	1.23	23
Denmark	0.67	6.96	22
Austria	0.67	14.44	22
China	0.67	11.62	22
Sweden	0.66	6.76	21
Spain	0.65	10.15	20
Norway	0.64	7.18	19
Australia	0.64	10.60	19
Korea (South)	0.63	6.18	18
Israel	0.63	11.78	18
Finland	0.62	2.21	17
Singapore	0.61	2.82	15
Russian Federation	0.61	7.27	15
India	0.61	2.63	15
Portugal	0.57	0.34	11
Ukraine	0.57	0.58	10
Poland	0.57	1.52	10
Saudi Arabia	0.57	0.21	10
Greece	0.56	0.08	9
Brazil	0.55	0.80	8
Luxembourg	0.54	0.18	7
Ireland	0.54	0.00	7
New Zealand	0.54	0.00	7
Malaysia	0.54	0.10	6
South Africa	0.54	0.07	6
Hungary	0.54	0.00	6
Slovenia	0.54	0.16	6
Argentina	0.53	0.13	5
United Arab Emirates	0.53	0.00	5
Mexico	0.53	0.00	5
Taiwan	0.53	0.00	5
Turkey	0.53	0.00	5
Romania	0.53	0.00	5
Virgin Islands	0.52	0.00	5

Table 2: Network Statistical Measures of the Cooperation Network